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CONDITIONAL SAMPLING, BOTTOM PRESSURE AND DENSITY ARRAY MEASURE--ETC(U)
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FINAL REPORT.
N0014-80-C-0351

NR-083-524

Conditional Sampling, Bottom Pressure and Density Array Measurements in HEBBLE.

Department of Earth Sciences
University of New Hampshire

11 1980

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INTRODUCTION:

The objective of the HEBBLE program is to understand the various chemical, geological, physical, and biological processes occurring in the Benthic Boundary Layer (BBL) in the high energy region of an undercurrent. Many investigators have been working on this project since 1977. (See the HEBBLE workshop reports of 1978, 1979, and 1980, as well as the HEBBLE NEWSLETTERs and the abstracts of papers presented in San Francisco in Dec. 1980 at the AGU Meeting.)

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The UNH portion of this effort during ~~the past~~ year lay in exploring three basic areas and consolidating our interests into a proposal for participation in the HEBBLE measurement program. The three areas of HEBBLE effort this past year are: 1) General participation in HEBBLE planning/ meetings; 2) exploration of the signal levels and our ability to make moored density array measurements in the BBL; and 3) development of conditional sampling techniques in relation to the central instrument package. Our proposal, "A Study of the Deep Flow in the HEBBLE Region," ~~(see~~ Appendix A) has been prepared and submitted. It proposes to move our present work in bottom pressure gradient measurements from the continental shelf into the deep ocean. This type of measurement appears to work well on the shelf, and we believe it could monitor fluctuations in the large scale flow in HEBBLE and provide a context for the more detailed boundary layer-sediment dynamics studies. Figure 1 shows the transport fluctuations from the New England Continental Shelf measured from pressure gradients as the solid line, and that measured by current meters as the dashed line. The agreement is good. The discrepancy in Feb. 1980 can be attributed to density changes in the water columns which could have been measured with a moored density chain.

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MOORED DENSITY ARRAY:

A moored density array would measure the temporal signatures of the processes acting in the BBL. We expected these would include the tides, internal waves, and the larger scale density adjustment associated with the geostrophic currents.

Our work in the Gulf of Maine shows strong tidal currents over the shallow banks on the edge of the shelf which could transfer energy into internal tidal oscillations. On the Pacific Coast, the geometry is such that these waves can propagate into the deep ocean, transporting energy to the bottom, which might help suspend sediment. With the KNORR CTD data taken by Zanesveld and the detailed bathymetry charts, this possibility was examined for the HEBBLE site. There appears to be no way that internal tidal energy can propagate to the HEBBLE site from the shelf break. The shelf slope is too gentle compared with the internal tidal characteristic.

Examination of the CTD profiles also shows a well-mixed layer with an adiabatic temperature gradient ($\sim 1.5\mu^{o}C/cm$) in the bottom 150m (the vertical

Letters on file

A

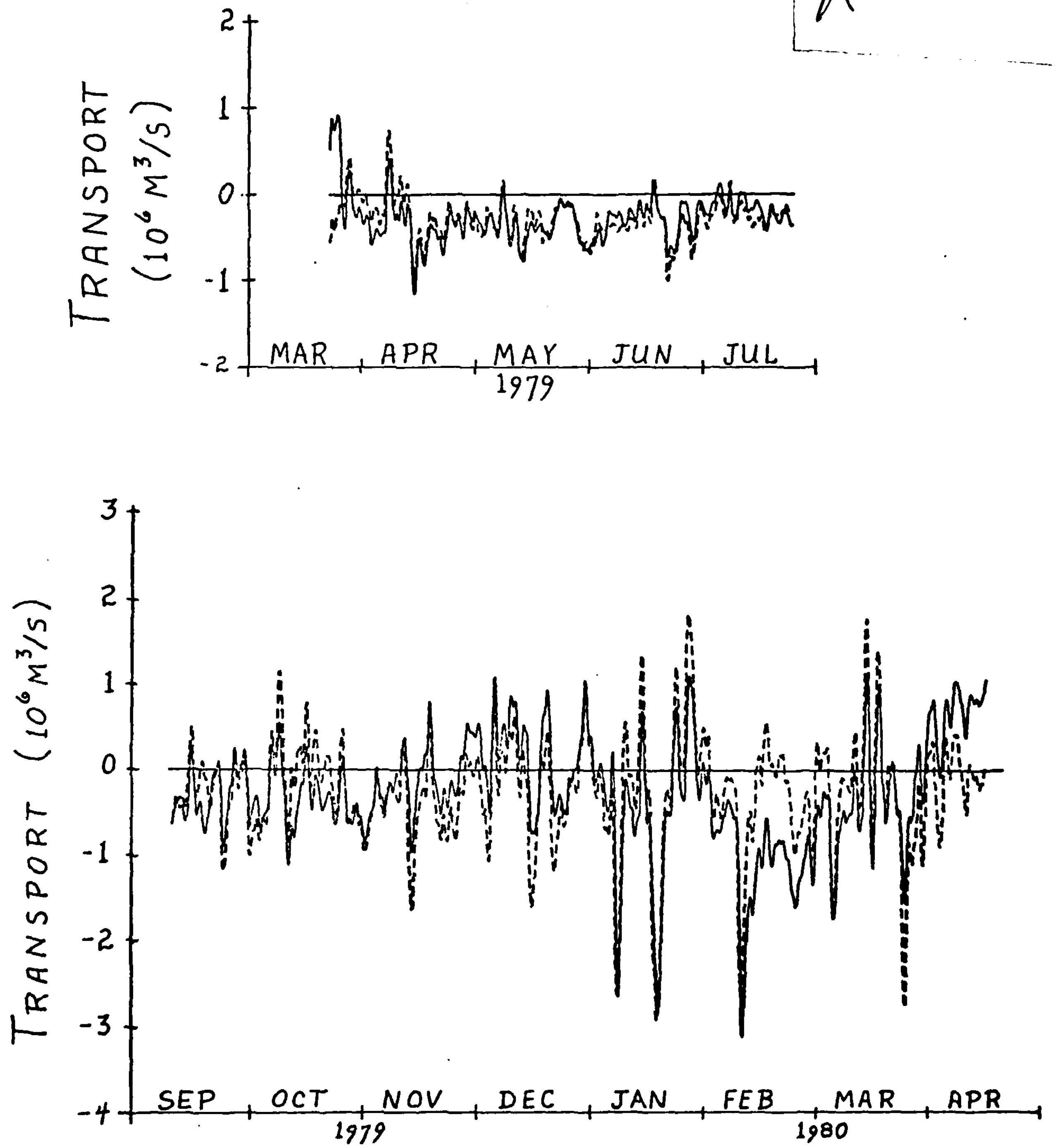


Figure 1

extent varies greatly with time and position). It would be impossible to measure this gradient with a moored array, but the adiabatic gradient could be used to intercalibrate the sensors on an array once it is in place. The fluctuations at a sensor are expected to be several hundredths of a degree C which can easily be resolved by the Sea Bird sensors we use. Moored conductivity fluctuations are expected to be several hundredths of a milliohm/cm, which could barely be resolved, being about equal to the drift rate of the sensor over several months. The T-S relationship in this region is not unique enough to distinguish water type and help identify the water source. To monitor the depth of the top of the mixed layer, numerous sensors would be required. Therefore, it appears that the main benefit of a moored density array would be to resolve the density fluctuations associated with the geostrophic flow in the region.

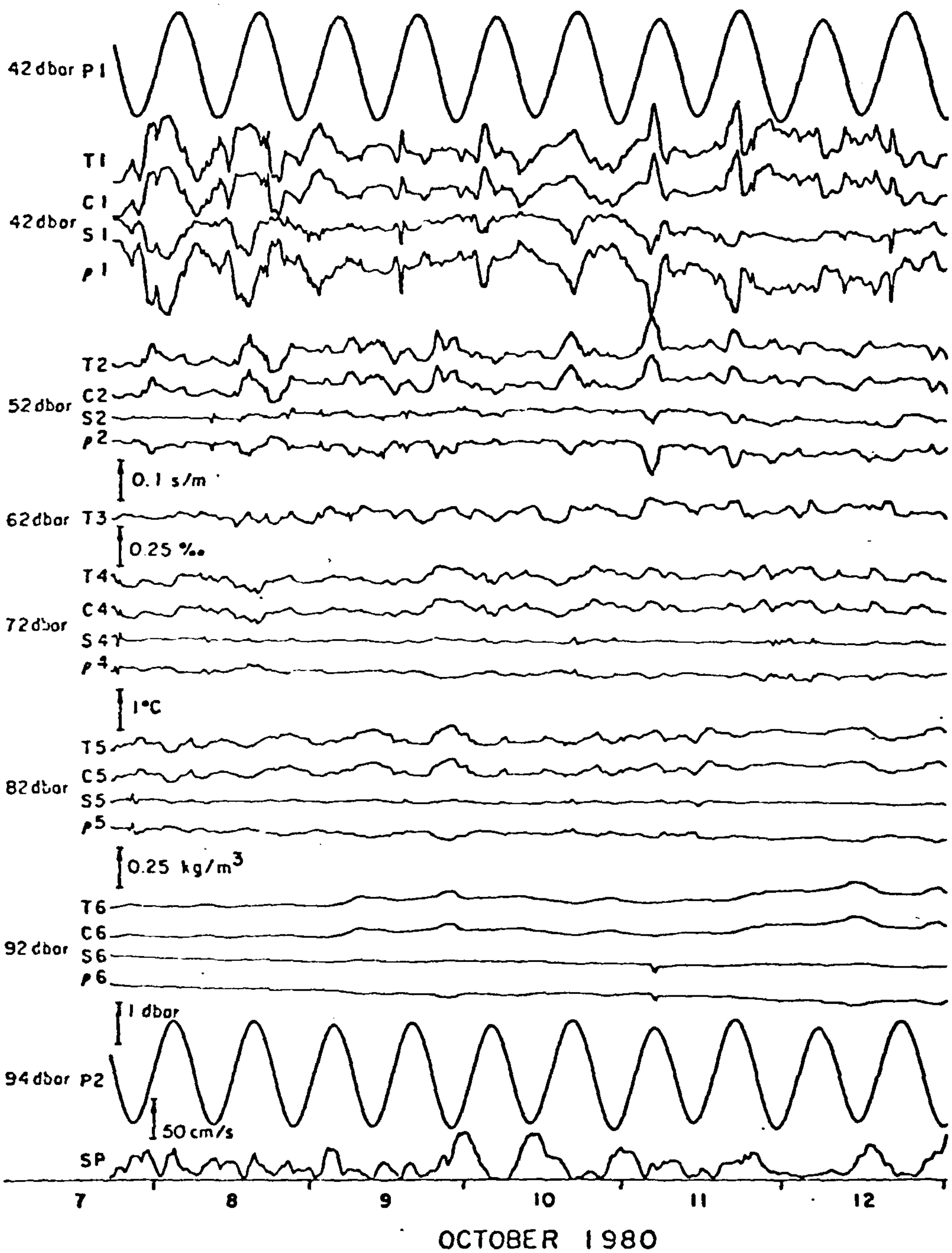
A developmental density array was deployed in Massachusetts Bay in Oct. 1980 for a week in preparation for CODE (Coastal Ocean Dynamics Experiment, funded by NSF). The data returned is shown in Figure 2. There was no apparent change in calibration of the sensors, and the results compared well with CTD profiles taken during the first few hours. The computed series of salinity and density are also shown. Features which exist in temperature and not salinity can be seen, as well as salinity features not seen in temperature. The test was successful, and a three month deployment was made as a part of CODE in the spring of 1981.

There would be only minor modifications to prepare a density chain of this type for use in HEBBLE. Deep ocean sensors could be added to a UNH bottom pressure instrument, or, with Sea Data electronics cards, to the FSU current meters. WHOI is now in the process of adding Sea Bird conductivity sensors to several of their VACM's for CODE.

CONDITIONAL SAMPLING:

To meet the rapidly changing requirements of remote oceanographic data collection, UNH is developing microprocessor-controlled data recorders. Four of these units have been built as a part of the CODE program. Each of them has two modes of operation, a low frequency average and a high frequency conditional sample rate. The microprocessor recorders can be interfaced with a variety of sensors. Currently, each reocrds fifteen minute averages from six pairs of temperature and conductivity sensors, as well as from a bottom pressure sensor. It also records water speed near the bottom, pressure at the top of the array, and the temperature of the bottom pressure sensor. The instrument conditionally samples the data and is capable of recording fifteen second samples, as well as the fifteen minute averages. The flexibility of such systems is great. We have designed the hardware around a "building block" principle, so a system can be easily adapted to record in any configuration with any number of sensors. The software is also designed so that subroutines can be assembled to create new improved sampling packages tailored to a particular experiment. A considerable amount of effort was spent on this development, and we consider the potential of the instruments well worth the development.

The advantage of a microprocessor system is that sophisticated sampling schemes can be easily implemented and modified. The variety and type of sampling seem to be limited mainly by the time required to write and test



Measurements taken in Massachusetts Bay with a conditionally sampling density array. In addition to the 20 minute averages shown, the instrument recorded high frequency "conditionally sampled" data.

Figure 2

the software. Our thoughts on conditional sampling have been evolving during the last two years, and will continue to evolve. Our current state of thinking is described below, as well as in two reports (see Appendix B and C).

Each sample interval (fifteen seconds) the microprocessor reads the digitized signal from each sensor and stores it in its memory. Using this data set, the microprocessor calculates a running sum and variance for sixty samples. This sum for each sensor, plus variance and current sample number, is written to tape every fifteen minutes. This sum is identical to the fifteen minute sample taken by discrete electronics counting over the entire fifteen minute interval.

The microprocessor's memory holds the most recent sixty samples from each sensor. The conditional sampling algorithm is applied to this data every time a new sample is added (every fifteen seconds). To examine the high frequency content of the data, we use digital filtering techniques. A first difference is taken to prewhiten the data. A filter is then applied, which suppresses tidal and lower frequency variations. What is left is the high frequency energy. We then calculate an "intensity" (the rms of the filtered data)., which is a weighted sum of past values with a sixty sample decay time. We define that an "event" has occured when the intensity exceeds a critical value. We let the microprocessor choose this critical value, or "adapt" its sampling to the observed geophysical signals. The critical is set to the mean plus two standard deviations of the intensity. If the intensity has a gaussian disrtibution, this critical should be exceeded about five percent of the time. The data stored in memory are not altered by the conditional sampling process. When an event is detected, the previous sixty samples are recorded on cassette tape.

In CODE this algorithm is applied to the bottom pressure, to all six temperatures on the array, and to three salinity series. We obtain the salinity by computing it from measured temperature and conductivity. The microprocessor converts the counts to geophysical value, and applies a linearized equation of state to estimate salinity.

Two reports have been published on our work on conditional sampling which were, in part, supported by HEBBLE. They are included as Appendix B (to be published in the OCEAN '81 proceedings), and Appendix C (a UNH Tech Report). With the development of the conditional sampling algorithms and the computer studies discussed in Appendix C, the groundwork has been laid to revise the algorithm to identify sediment transport events.

A STUDY OF THE DEEP FLOW IN THE HEBBLE REGION

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Introduction

The principal goal of the High Energy Benthic Boundary Layer Experiment (HEBBLE) is to study the sediment dynamics and transport in a highly energetic region of the deep ocean. As such, the initial emphasis of HEBBLE will be on detailed studies of the combined hydro-sediment dynamics on horizontal scales of tens of kilometers within 100m of the sea floor. In addition, it will be important to acquire a description of the larger scale flow that affects the region so that the representativeness of the HEBBLE results can be assessed. For a detailed discussion of the scales and relationships between the flow and sediment studies, see Arthur Nowell's excellent discussion given in Hollister et al., 1980.

Previous observations by HEBBLE participants Wimbush and Weatherly and others in the HEBBLE area (figure 1) indicate that intermittent near-bottom currents of up to 73 cm/sec may be responsible for producing the bedforms and suspended load found there. Observations to the east and south of the HEBBLE area, summarized by Schmitz (1976, 1977, 1980), Hogg (1979), and Tarbell et al. (1978), suggest that larger scale 4,000m depth current fluctuations with periods of about a month (figure 2) are part of the circulation associated with the Gulf Stream, Western Boundary Undercurrent and a deep gyre system which appears to be trapped by the seafloor mountain chains.

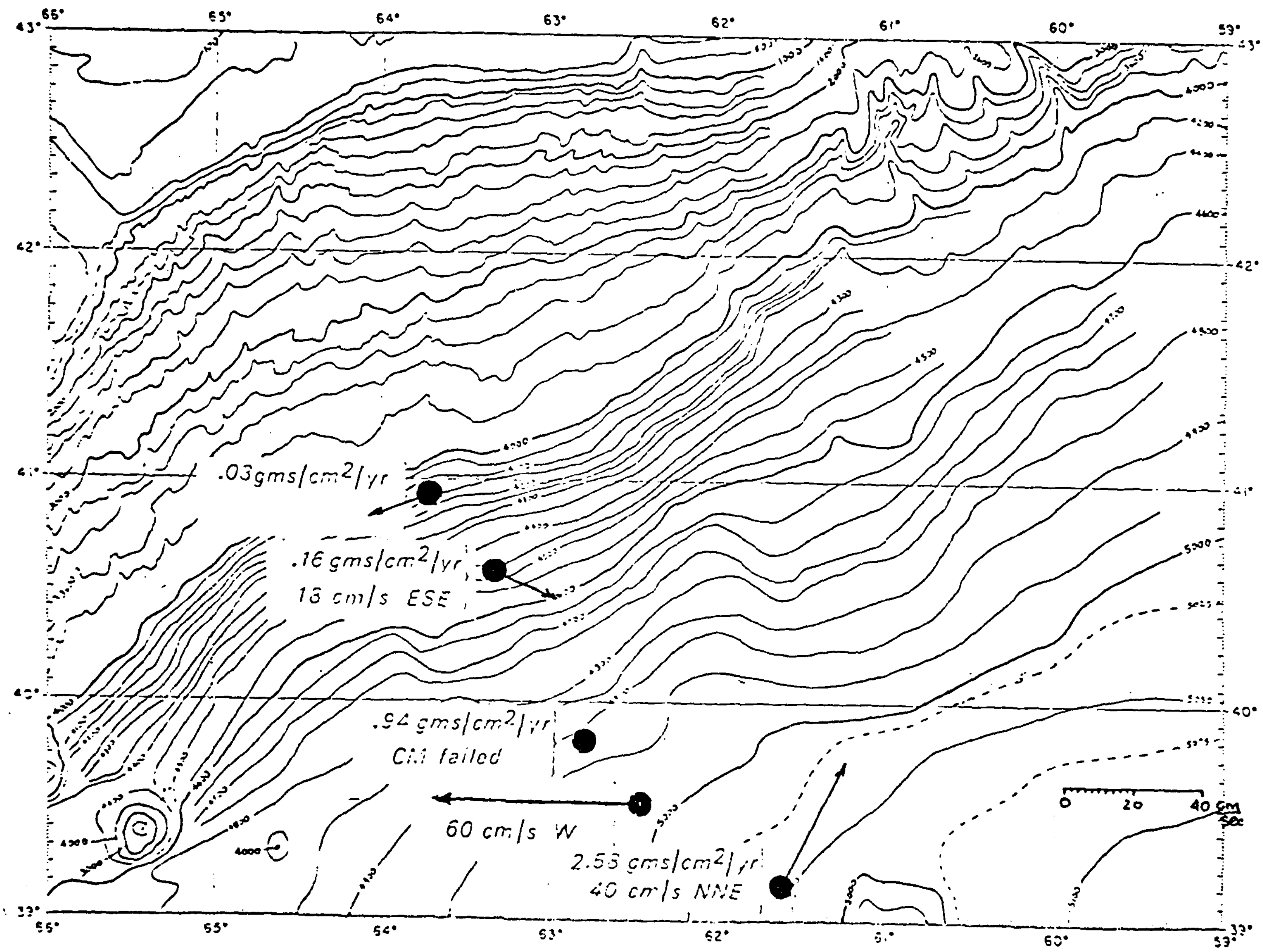


Figure 1. The HEBBLE site on the Nova Scotian rise. The current meter velocity averages over 16 days are shown along with some sediment trap results from KNORR 74.

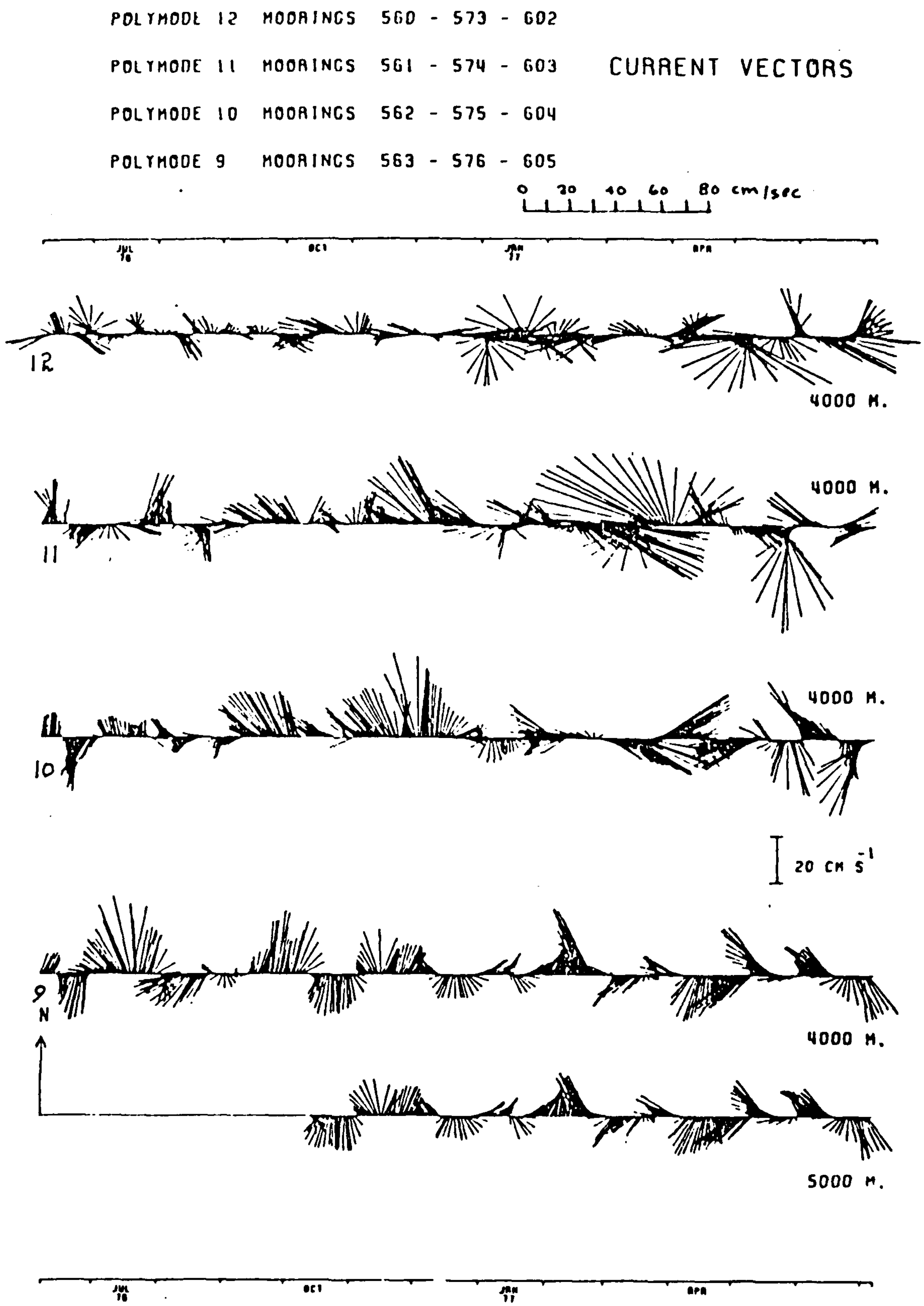


Figure 2a. Current vector stick diagrams from the POLYMODE II array. Note the 50cm/sec event in mooring 11 during March. The variability of the currents is large, and the coherence scales are of the same order as the array spacings O(100 km). (Tarbell et al. 1978)

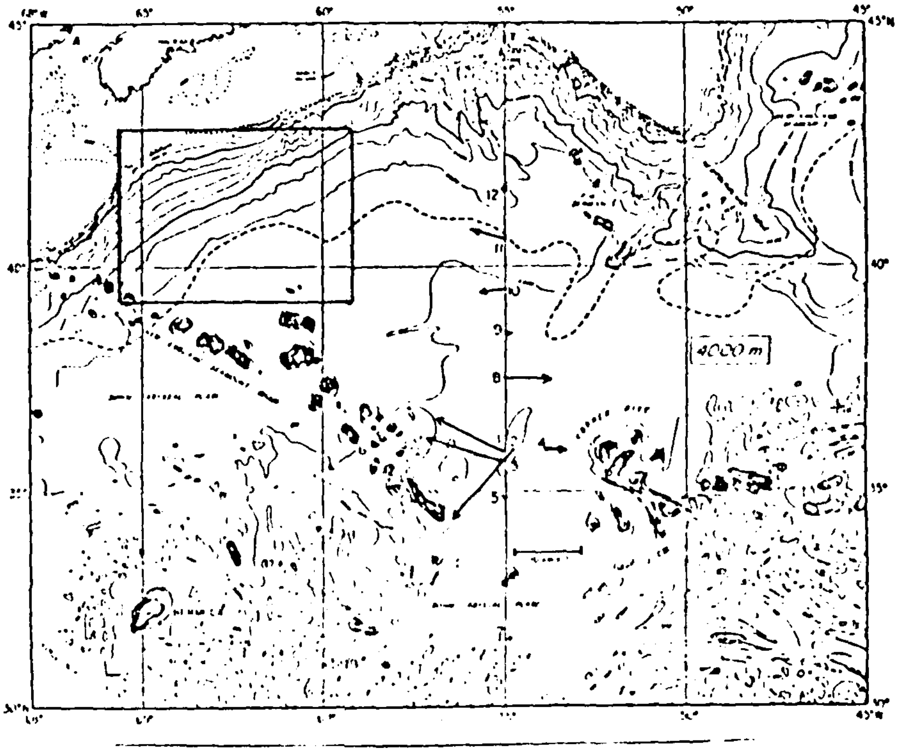


Figure 2b. The POLYMODE II mean currents are shown relative to the boxed HEBBLE area. (Schmitz, 1980)

Although POLYMODE observations suggest that these current events are nearly depth-independent, the vertical structure of these features beneath the main axis of the Gulf Stream and in the HEBBLE area remains unknown. There is also unusually large temporal and spatial variability of the temperature and salinity field in the HEBBLE area which appears to be located in the mixing regime of Antarctic Bottom, Denmark Straits Overflow and North Atlantic Deep Waters. Therefore, in a location with such great current, temperature, salinity, and suspended sediment variability, it is important to allocate sufficient resources in order to obtain an adequate description of the near-bottom oceanic conditions.

At UNH we propose a component of HEBBLE which will complement and extend the work of Weatherly (FSU) and Wimbush (URI), and will help to provide important additional information regarding the spatial and temporal variability of the larger scale currents, temperature/salinity and suspended sediment field in the HEBBLE region. As such, it will be one component of the HEBBLE physical oceanography studies, which can be divided conveniently (though artificially) in terms of the vertical (δ) and horizontal (X) scales of the following boundary layer regions:

a) Inner Layer $\delta_{IL} = O(10m)$ $X_{IL} = O(1km)$

b) Benthic Boundary Layer $\delta_{BBL} = O(100m)$ $X_{BBL} = O(10km)$

c) Outer Flow $\delta_{OF} = O(1000m)$ $X_{OF} = O(100km)$

Inner Layer studies will be concerned with providing an increased understanding of the turbulent processes which resuspend, transport and deposit sediment in terms of the flow in the Ekman layer. Here an understanding of the vertical structure of the dynamics is of primary importance,

and thus a major proportion of the instruments will be deployed on the master lander in near-bottom vertical arrays.

The FSU Benthic Boundary Layer studies of Georges Weatherly will be concerned with the dynamics of the oceanic Ekman layer in the presence of suspended sediment. The horizontal scales of this flow within 100m of the seafloor will be explored over tens of kilometers with several current meter/temperature moorings.

We believe that the principal purpose of the Outer Flow studies in HEBBLE should be to monitor the condition of the larger scale deep ocean flow which influences the Ekman and Inner Layer flows. There are several types of information which can be acquired with different levels of effort. (1) At the very least, the Outer Flow studies should be able to provide on-site outer flow intensity information about the particular events whose effects are being observed in more detail by others at the main HEBBLE site. (2) If questions regarding the "regional representativeness" of the HEBBLE site observations are to be addressed, then the outer flow studies should provide frequency and spatial scale information regarding the type of flow events which affect the HEBBLE site. (3) Questions pertaining to the actual transport of the sediments through the HEBBLE site can be addressed with an increased effort plus the coordination of the Benthic Boundary Layer and Outer Flow study groups. (4) An even more ambitious effort, which might include coordination with efforts outside HEBBLE, would provide increased understanding of the dynamics of the flow events affecting the HEBBLE site, and by doing so would help to put HEBBLE observations in a global ocean perspective.

Short-Term Monitoring

A single vertical array of current meters and temperature/conductivity sensors deployed at the HEBBLE site for the six-month experiment will provide a time description of the local current and density field. With the addition of the less-well-instrumented FSU moorings with spacings of 10-20km around the central lander, the horizontal extent of a particular event can be monitored also. (The array configurations and locations are shown in figures 3 and 4, respectively.)

Estimates of Time and Length Scales

If the temporal and spatial scales of a "typical" sediment resuspension event are to be described, then we must acquire enough information so that stable statistics of these quantities can be computed. For the outer flow variability (see figure 2a) we expect that, in the HEBBLE region, this means the horizontal extent should be 100km and the duration of the current meter deployment should be more than a year.

We propose to extend the FSU current array by deploying an additional four vector-averaging current meters at the 100m "control elevation" at the four locations shown in figure 4. Three six-month deployments of this array will provide information for estimating the along and across-rise length scales of the important sediment suspending flows in the HEBBLE area. Improved estimates of the 100 meters-above-bottom (mab) current coherence length scale will be possible if additional information is provided by the

Figure 3. A proposed array layout, particularly for the UNH pressure/density array. Other sensors than are shown are scheduled for the central mooring.

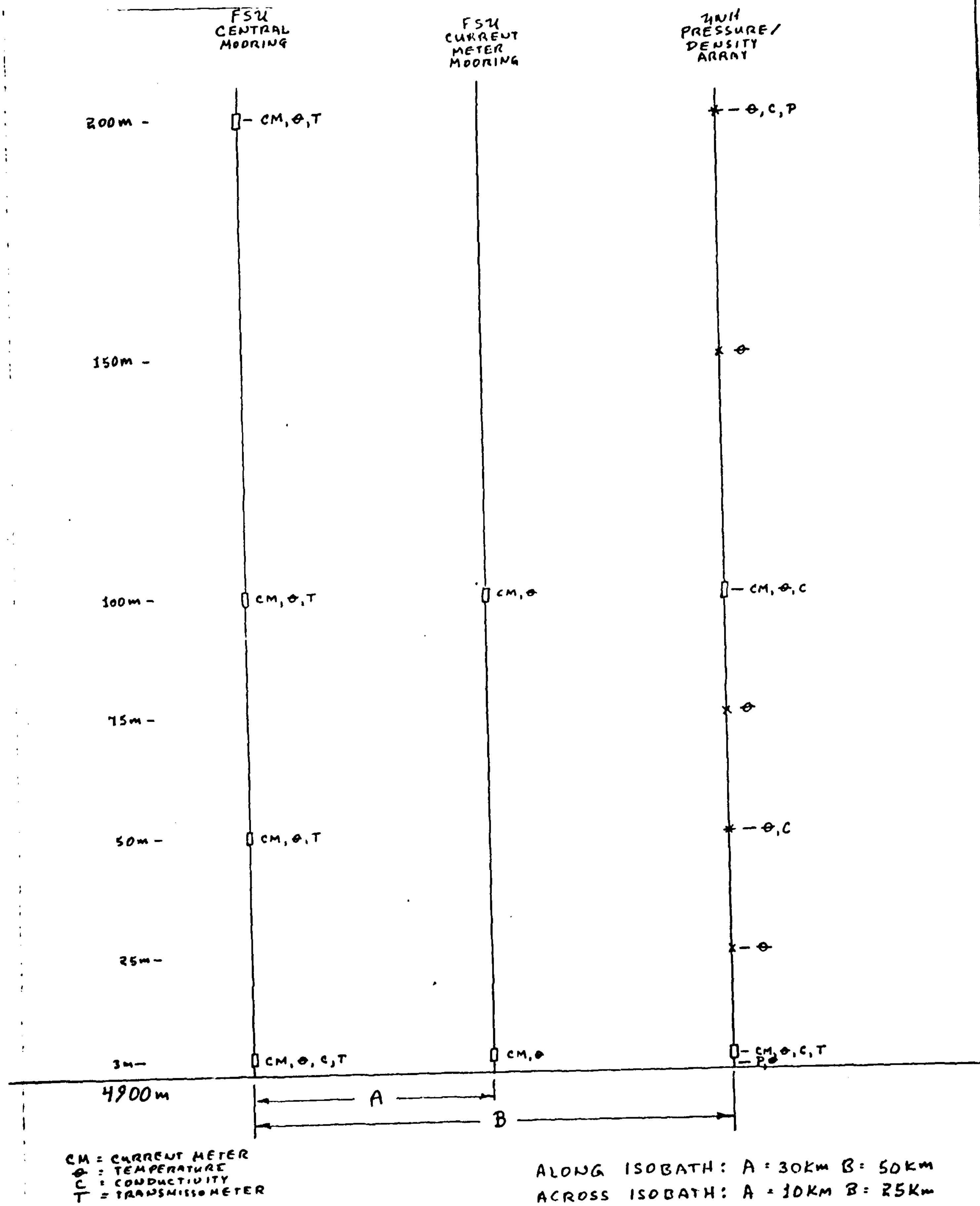
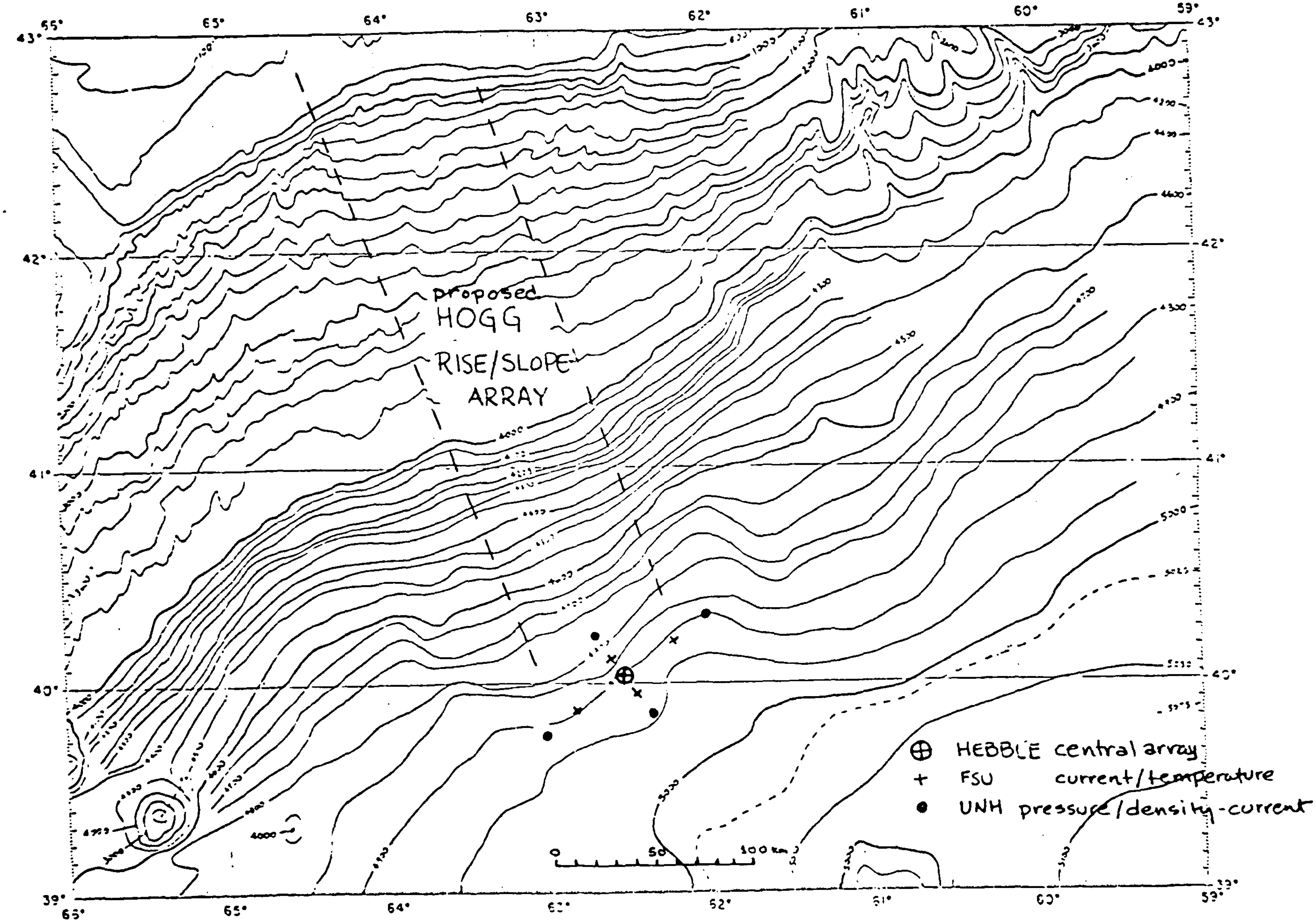


Figure 4. A proposed array at a proposed HEBBLE site shows the relationship of the moorings and the relationship with Hogg's proposed Rise/Slope experiment site.



Continental Rise/Slope array planned by Nelson Hogg for an adjacent site (see figure 4). A tentative picture of the vertical resolution of that planned array is shown in figure 5.

Suspended Sediment Transport Estimates

Accurate estimates of large scale suspended load transport require considerable resources to resolve both current and suspended load spatial scales. Nevertheless, estimates of local suspended load transport will be provided during HEBBLE by the combined FSU current and OSU transmissometer measurements.

Larger scale estimates of suspended load transport could be obtained with extended horizontal coverage with vertical arrays of current meters and transmissometers. However, we propose a less expensive alternate method which employs pairs of bottom pressure and density profile measurements to estimate geostrophic transport.

For the simple flat bottom ocean case it can be shown that the geostrophic transport, $T(t)$, normal to a vertical plane with dimensions Δx, Δz is related to the bottom pressure differences, δp_b, and density anomaly differences, $\delta\rho'$ across Δx according to

$$T(t) = \frac{1}{\rho_0 f}\left[\underbrace{\delta p_b \,\Delta z}_{(A)} - \underbrace{g \iint_{\Delta z} \delta\rho'(z'')dz''dz'}_{(B)}\right]$$

This relation shows that fluctuations in large scale geostrophic transports can be estimated directly from a pair of bottom pressure sensors, which are used to estimate term A, and a pair of density chains, which provide the information for estimating the correction term B.

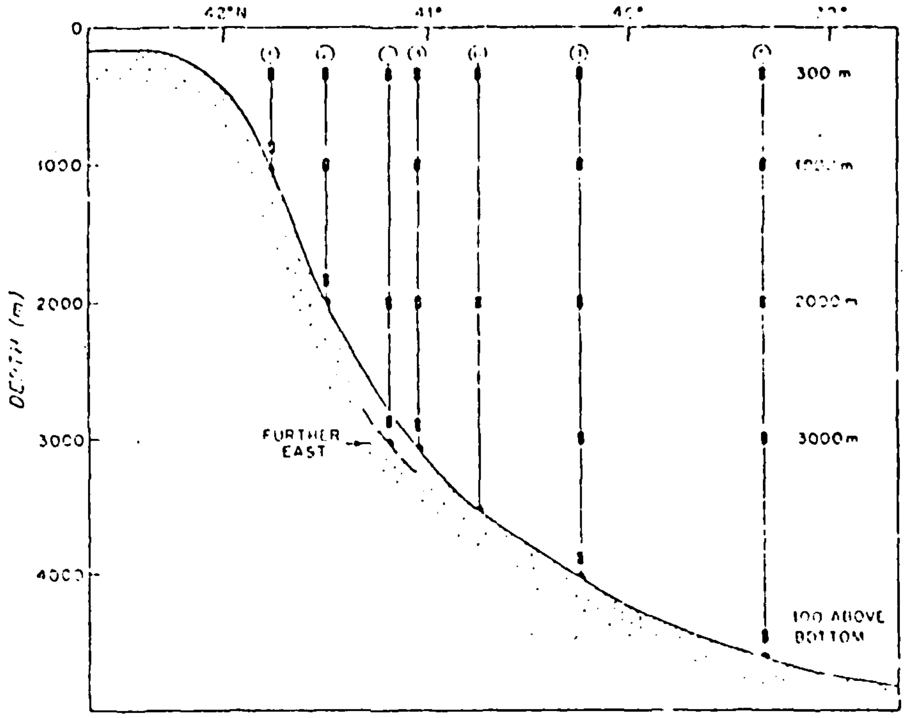


Figure 5. The proposed current meter depths from Hogg's proposed array shoreward of the HEBBLE site.

During HEBBLE we propose to deploy an across-rise pair and an along-rise pair of bottom pressure/density chain stations (an example is shown in figure 3) for the purpose of estimating the geostrophic transport vectors for that region in figure 4 bracketed by UNH pressure stations. An analysis combining these and suspended load results will permit us to make suspended load transport estimates, which can be compared with those made using the current meter arrays. The FSU current profile measurements in the Ekman layer will permit us to assess the error in our method which is due to our assumption of geostrophic flow.

We propose the deployment, during a six-month period before the HEBBLE experiment, an across-rise bottom pressure/density chain pair for purposes of (a) testing hardware (in particular, bottom pressure sensors), and (b) exploring the horizontal scales of the pressure field. An additional one-year deployment of the across-rise pair following HEBBLE will provide the information required to compute representative statistics of the "transport field."

Bottom Stress Estimates

Others in HEBBLE will concentrate on studying the near-bottom processes which lead to sediment resuspension. Part of those studies will include measurements used for estimating local bottom stress. The difficulty in interpreting such single-point measurements in the presence of bottom topography and density stratification (due to both T/S and suspended load) is well known. Here we propose to use the flow measurements described above with an integrated form of the momentum equation to provide estimates of the area-averaged hydrodynamic bottom stress. Although this is not the same

quantity which resuspends sediment grains, it is related to it so that information of this type will be useful in characterizing the regional bottom stress field.

This bottom stress inference method is based on a volume-integrated form of the momentum equations for which we estimate from measurement all terms except stress. The area-averaged bottom stress, $\langle \tau^b \rangle$, can be inferred as shown schematically

$$\langle \tau^b \rangle = \boxed{\text{inertial}} + \boxed{\text{Coriolis}} + \boxed{\text{non-linear}} + \boxed{\begin{array}{l}\text{Reynolds}\\ \text{Stress}\end{array}} + \boxed{\begin{array}{l}\text{surface}\\ \text{stress}\end{array}} + \boxed{\begin{array}{l}\text{pressure}\\ \text{gradient}\end{array}} .$$

Then the right-hand side terms are estimated from current meter and density measurements made over the whole water column and bottom pressure measurements bracketing the bottom area of interest. Since our volume integral covers the whole water column, we must also depend on information from the rise/slope array planned by Nelson Hogg for its application to the HEBBLE area.

Conditional Sampling of Important Events

Phenomena such as sediment resuspension and transport are intermittent in time. To properly sample these events, high frequency sample rates (i.e. minute scales) are required; while to resolve the variations of the large scale flow, long deployments (i.e. year scales) are required. With the limited storage space in remote instrumentation, some form of conditional sampling is required to initiate the recording of high frequency information

only during "interesting" events. Otherwise, only low frequency information is recorded.

We have been studying conditional sampling of continental shelf pressure, temperature and density measurements for the past few years. Several deployments of microprocessor-controlled instrumentation have been made which show the power and flexability of remote computers for specialized sampling. In the UNH instrumentation we will adapt our existing software and experience with conditional sampling to the sampling problems we expect to encounter in HEBBLE.

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Tarbell, S., A. Spencer, R.E. Payne, A compilation of moored current meter data and associated oceanographic observations, Volume XVII (POLYMODE Array 11 Data), Woods Hole Oceanographic Institution, Tech. Rept. WHOI-78-49, 1978.

WORK STATEMENTS AND COST ESTIMATES

I. TASK ONE: Construct two microprocessor-controlled, conditionally sampling, bottom pressure, density array instruments for deployment in NOV 1981 from KNORR with recovery in MAR 1982.

A. Construct two bottom instruments with microprocessor-controlled data loggers which will allow additional sensors; vector averaging current meter capability; conditional sampling and data telemetry. The instrumentation would be copies of those we have developed for use in CODE. They are modular in construction to allow easy adaptation to any experiment. An acoustic release, flotation, and battery pack are mounted with the electronics in a frame.

The basic instrument (without sensors) costs around $33K each. To these basic instruments we would add the pieces described below. The basic instrument would also have an acoustic data telemetry system we have been developing and will test in CODE.

B. Pressure sensor capability. The limitation to deep ocean pressure gradient measurements is the noise spectrum of the sensors themselves. Possible sensors are (1) the Paroscientific quartz force balance sensor which we have used for pressure gradient measurements on the continental shelf. It is now available in a 10,000 PSI unit for under $4K. (2) the Hewlett-Packard quartz sensor first used in MODE. Wimbush has a unit specially built for work

near $0^{o}C$ which he is willing to lend to this study. We would propose to use two sensors on each instrument, one Hewlett-Packard and one Paroscientific sensor. This would require the purchase of one Hewlett-Packard at $20K, as well as two Paroscientific sensors for a total of $28K. In Task Two, the additional sensors would then be used on instruments made available after CODE to complete the bottom pressure sensor array. The pair of sensors would allow the noise spectrum to be calculated by cross spectral techniques.

C. Density array. We propose to use the Sea Bird temperature and conductivity sensors. Temperature appears stable to within three millidegrees between sensors for six-month deployments. Conductivity sensors have been the weakness of density measurements. Our experience with the Sea Bird sensors on the New England shelf indicates they should be stable enough for $0.1^{o}/_{oo}$ in salinity over six months. Shorter term fluctuations are easily resolved to $0.001^{o}/_{oo}$. We believe the weakness of these sensors would be the effects of contamination of the cells by suspended particulate matter. We believe that much of the "noise" seen on the shelf 0.5m off the bottom is due to SPM. We would propose an array of seven temperature and four conductivity sensors on each of the two arrays. The sensors, with calibration, would cost $15K per array with array cabling and fairing $4K each and glass sphere flotation $4K each. A Paroscientific pressure sensor at the top would monitor array motion. The total cost per density array would be $27K.

D. Conditional sampling. We have been working on conditional sampling ocean pressure signals for such high frequency events as tsunami, and conditional sampling moored density for internal wave and advective events on the continental shelf as part of CODE. We would continue to interact with HEBBLE investigators and JPL on conditional sampling on the central lander, and pursue our own investigations on the density array outstations. The cost of conditional sampling is for people time for software development and testing. We anticipate that $10K of investigator and programmer time would be required to produce, test, and implement a conditional sampling program.

E. Vector averaging current meters. We have constructed prototype circuitry to prove the feasibility of converting film recording current meters to microprocessor VACM's. We could convert instruments to add to the 100m level of the arrays. These instruments would be self-contained current meters which could be expanded to record temperature, conductivity, pressure or transmissometer signals, in addition to conditional sampling. Cost of conversion is estimated to be around $8K each which includes a new compass and vane follower, and complete mechanical rework.

II. TASK TWO: Rework two CODE density chain instruments to give deep ocean capability. This would involve adding 10,000 PSI pressure cases ($1K each), purchasing density array sensors, cabling and fairing ($19K each), and replacing and repairing CODE damage to frames, etc. ($5K each). Software would be modified based on preliminary findings;

array spacing would also be modified as the experiment progresses. Main deployment would be made in 1983 with the rest of HEBBLE.

III. TASK THREE: Analysis

Reduce our results to preliminary form, distribute our measurements, and acquire those of others. Once the data base is complete, analyses for large scale motion, bottom stress climatology, etc., as discussed above can be addressed.

IV. CTD SURVEY: One element vital to the large scale circulation is the CTD survey results. The CTD work is important to all the physical oceanography, and should be budgeted and planned as part of one principal investigator's responsibility. We propose that a working subgroup of HEBBLE investigators meet regularly to discuss the needs of the surveys and see that the necessary standards are met so the various HEBBLE measurements can be intercompared.

HEBBLE BUDGET

	FY 81	FY 82	FY 83	FY 84
	1 MAR 81 30 SEP 81	1 OCT 81 30 SEP 82	1 OCT 82 30 SEP 83	1 OCT 83 30 SEP 84
A. SALARIES & WAGES	MOS.	MOS.	MOS.	MOS.
1. James D. Irish Principal Investigator	4	5	5	5
2. Wendell S. Brown, " "	-	-	1	1
3. Mark P. Woodbury, Project Engineer	4	5	5	3
4. Edward LaCoursiere, Field Engineer	4	6	6	4
5. Alvin Bugbee, Programmer	3	4	6	8
6. Hourly Technical Help	3	4	4	4
7. Secretary	1	1	1	1
TOTAL	19 25.6K	37K	46.7K	47.5K
B. BENEFITS (19% of A)	4.9K	7K	8.9K	9.0K
C. TOTAL OF A & B	30.5K	44K	55.6K	56.5K
D. PERMANENT EQUIPMENT	146K	90K	10K	-
1. 2 μP Instruments Less Sensors	48K			
2. 1 HP & 2 Paros Pressure Sensors	28K			
3. 2 Density Arrays Complete	54K			
4. 2 VACM Conversions	16K	16K		
5. Convert CODE μP to HEBBLE		12K		
6. 2 More Density Arrays		52K		
7. Misc. Rework & Replacement Parts		10K	10K	
E. EXPENDABLES	6K	5K	4K	1K
F. COMPUTING	1K	2K	3K	4K
G. TRAVEL: DOMESTIC	2K	5K	6K	4K
1. To Meetings (Scientific & Planning)	2K	3K	3K	3K
2. For Cruise		2K	3K	1K
H. PUBLICATION COSTS	1K	1K	2K	3K
I. OTHER DIRECT COSTS	3.5K	4K	5K	3K
1. Calibrations	.5K	1K	1.8K	1K
2. Office (Phone, xerox, etc.)	1.5K	1.5K	1.7K	2K
3. Small Boat Time @ $500/day	1.5K	1.5K	1.5K	
4. Ship Time (Assume no cost to UNH)	-	-	-	-
J. TOTAL DIRECT CHARGES	190K	151K	85.6K	71.5K
K. OVERHEAD (47% of J less D)	20.7K	28.7K	35.5K	33.6K
L. TOTAL COSTS	$210.7K	$179.7K	$121.1K	$105.1K

Appendix B

Conditional Sampling of Oceanic Variability with Microprocessor-Controlled Instrumentation

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ABSTRACT

To optimize the limited cassette tape storage capacity of remote oceanographic instruments, we are employing various "conditional sampling" schemes. These make use of the power of a microprocessor-based data logger to sample the environment "conditionally." The microprocessor examines the energy in various frequency bands (by digital techniques) and adjusts its sampling scheme to sample the appropriate frequency band. We have implemented a conditional sampling scheme on a microprocessor-based instrument and used it in several deployments on the continental shelf. Our current conditional sampling scheme and some results are presented to show the advantage of using such sophisticated sampling techniques.

1. INTRODUCTION

Increased scientific need for long data series plus the desire to resolve the higher frequency fluctuations of many ocean parameters has placed requirements on remote oceanographic instrumentation which can not be met by fixed intervel recording on standard cassette recorders. In addition, the high frequency energy varies with time, so that a fixed sample interval generally will supply redundant data most of the time, and inadequate data during the rare times of an interesting event. A sampling scheme of intermittent rapid sampling superimposed on a low sampling rate (often referred to as burst sampling) is an improvement, but is generally not satisfactory due to the random intermittency of these high energy signals. We require a sampling rate conditioned by the occurence of the rare important events, which we will refer to as conditional sampling.

We are employing microprocessor-controlled bottom instrumentation to measure pressure gradient fields in the study of shelf circulation. These instruments also have vertical arrays of temperature and conductivity sensors to measure the contribution to the bottom pressure signal by the density field variations, and also to sense fluctuations due to interval waves, intrusions and mixing events. We utilize the microprocessor system to conditionally sample the various sensors and optimize the available capacity of the cassette recorder. For example, one could detect a tsunami as a high frequency event superimposed on the lower frequency tides and weather forced bottom pressure fluctuations. Other high frequency events might be due to the mixing at the front of an intrusion, or due to a breaking interval wave, and would contribute to the vertical mixing of heat and salt.

We use the term conditional sampling in the broad sense, to cover the various processes acting on the signals coming from the sensors which determine how the data are permanently recorded. In our instrument, this process includes the averaging done in counting the signal over the sample interval, a simple spike removal error detector, temporary storage of the last sixty samples, the specific event detector algorithm including variable sample intervals and adaptive sampling. These are discussed below and described in more detail in Ref. 1.

2. HARDWARE DESCRIPTION

The UNH microprocessor-controlled instrument is constructed around the INTERSIL IM6100 microprocessor. About half of the electronics space is directly related to the microprocessor (ie. CPU, memory, etc.) and the rest is associated with the sensors and acoustic systems. The system is constructed in "building block" fashion which allows the system to be easily adapted to each new application. The basic system consists of the IM6100 CPU, a Memory Expansion, RAM, EPROM, a UART, and a Sea Data Cassette Recorder. Up to three additional fields of memory (4096 twelve bit words per field) can be added. Each field can be entirely RAM, or up to 3/4 EPROM as the application requires. Currently software memory is structured with the operating system, math package, and basic conditional sampling software in one field. The data is temporarily stored in a second field of RAM. The acoustics and miscellaneous subroutines are contained in a third field. The system without sensors draws between six and fifteen milliamperes at 5.2 v dependent on the microprocessor's clock frequency, the number of sensors, and the amount of memory used. The system has been powered for up to four months on lithium batteries.

The data are permanently stored on a Sea Data digital cassette. This recorder plugs directly into the microprocessor's bus and operates under software control. One three hundred foot cassette can hold up to 10^7 bits. Currently, in a four month deployment, we record twelve thousand samples of fifteen minute averages from sixteen sensors plus time on half the cassette, and conditionally sampled data on the other half. A full cassette can be written with a two ampere hour, 18 v battery pack.

A clock card controls all the timing. It has a 4,194,304 Hz quartz crystal with 0.1 ppm/°C temperature sensitivity. The selected sample interval is hardwired on this card, which also contains a sample number counter that interfaces with the microprocessor's bus. The timing for all counter gates, latches, and resets are contained on the card, as well as an interrupt to notify the microprocessor when a new set of samples is ready for processing.

The microprocessor reads the sensor's signals through a sensor counter/interface card, which plugs into the microprocessor's bus. Each card interfaces with three sensors. The FM signal from each sensor is shaped to a 5 v square wave, and counted under timing control of the clock. At the end of each sample interval, the twelve least significant bits are transferred to a latch, the counter reset, and count on the next sample started. Since the timing for all sensors is controlled by the same clock, the sensor readings are all taken simultaneously. The microprocessor enables each latch sequentially through an I/O control card to transfer the count to the bus, and then stores it in RAM.

The instrument also contains an acoustic data telemetry system and alert similar to that described by Snodgrass[2], and an FSK data telemetry system which is currently under development. These systems allow the instrument to be checked when it is in place on the sea floor.

All sixteen sensors currently being used have an FM output. Pressure is measured with a Paroscientific Quartz sensor (See Ref. 3 for an evaluation of the sensor operation). Temperature is measured with a thermistor-controlled oscillator (Ref. 4) and conductivity with an electrode resistance-controlled oscillator (Ref. 5). These Sea Bird Electronics, Inc. temperature and conductivity sensors are mounted as pairs on a vertical array above the bottom pressure sensor. It should be noted that this form of conditional sampling does not save power by having the sensors and electronics turned off, but it optimizes the limited storage space available, and eliminates redundant data when interesting signals are not present.

4. THE CONDITIONAL SAMPLING PROCESS

The advantage of a microprocessor-based instrument is that sophisticated sampling schemes can easily be implemented and modified. The variety and type of sampling seems to be limited mainly by the time required to write and test the software. With successive deployments during the last two years, our thoughts on conditional sampling have been evolving. An instrument currently deployed in the Coastal Ocean Dynamics Experiment (CODE) contains our most recent schemes, and is described below and illustrated with examples from past experiments.

Each sample interval (fifteen seconds), the microprocessor reads the digitized signal from each sensor and stores it in RAM. The past sixty samples from each sensor are temporarily stored, and become the data set on which the sampling scheme will operate. There are two modes of operation. The first (referred to as low frequency sample) records data continuously based on time. The second is dependent on the high frequency content of the data and is our conditional sampling mode. The low frequency sample is formed by making a 24 bit sum from the 12 bit readings at the time they are being stored in RAM. In addition to the sum, a running variance is also calculated. Every sixty samples (fifteen minutes), the sums and variances from each sensor, plus an ID word and current sample number, are written onto cassette tape for permanent storage. The sum is identical to the result obtained by counting the sensor output over the entire fifteen minute interval by standard frequency counting techniques.

The most recent sixty samples of data (stored in RAM) contain information on frequencies between 4 and 20 cph. The low frequency samples contain information on frequency fluctuations up to 2 cph, and this is more than adequate resolution for the tides and weather-forced circulation. The conditional sampling algorithm is applied to the data in RAM every time a new sample is added. To separate out the high frequency content of the data, we use digital filtering techniques.

Most geophysical spectra are "red," or have higher energy at lower frequencies. (A spectrum of a bottom pressure record from the continental shelf sampled once per minute is shown for example in Figure 1.) A first difference (the present value minus the previous value) is taken to "prewhiten" the series. At this time, an error detection scheme is also applied. Whatever the cause, a "bad" value can dominate any further event detection scheme. Geophysical fluctuations are generally known well enough that a maximum expected first difference can be chosen. We identify a spurious datum as having a first difference greater than five times the maximum expected. The first differences are stored in another sixty sample array in RAM, and when a bad first difference is detected, the previous first difference is substituted.

The first difference suppresses low frequencies and amplifies high. However, the tidal energy typically is a decade or more greater and so still dominates the record (See Figure 1). To eliminate the tides and lower frequency fluctuations, we apply a filter of 5 weights (1.000, -3.99875, 5.9975, -3.99875, 1.00) with a lag of fifteen samples per weight. This filter extends over the entire sixty sample first difference array. The response of this digital filter is shown in

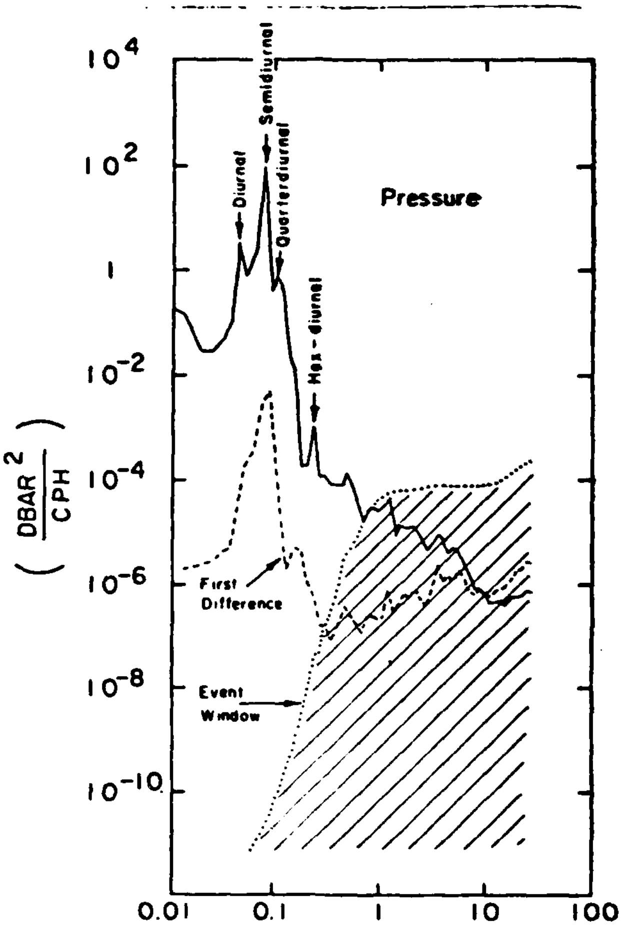

Figure 1. Spectra of shelf pressure. The observed record spectrum is shown by the solid curve. The dashed line is the spectrum of the first differenced signal. The shaded area represents the envelope of the combined filter effects and the energy on which the event detector operates.

Figure 2, low frequencies are suppressed by more than 70 db and tidal signals by more than 100 db. The combined filter effect is shown in Figure 1, where the energy remaining has passed through the high pass "event window." The low frequency content of the signal is satisfactorily recorded by the fifteen minute averages, and we can consider this high frequency signal separately.

The output from the tide filter is used to create an "intensity," which is calculated from

$$I(i) = 0.9235\ I(i-1) + 0.0165\,|\ \text{FILTERED SERIES}\ (i)|.$$

This is the weighted sum of past intensities, which decays to 1/e in sixty samples. A step in the original record becomes a single spike in the first differenced record and five spikes in the tide filtered record. The intensity would then show five jumps upward with a decay after each jump. The maximum intensity would be reached forty-five samples after the initial step. Hence,

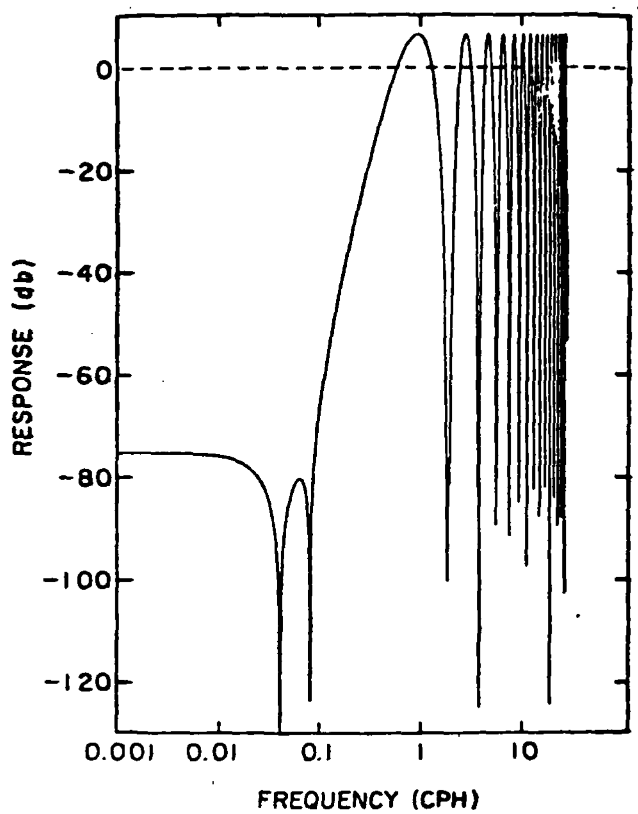

Figure 2. The response of the digital filter to select against tides and lower frequencies.

by recording the past sixty values, the initial step is recorded.

An event is declared when the intensity exceeds a critical value. In order to choose this value, the scientist needs previous knowledge of the expected high frequency signal level. When conducting an experiment in a new region, this is usually impossible, so we allow the microprocessor to choose the critical value. The mean and variance of the intensity are calculated from the start of the experiment, and the critical is set to equal the mean plus two standard deviations. Thus, if the distribution were normal, the critical would be exceeded between 2 and 3% of the time. As Figure 3 shows, the statistics of this calculation are not very good near the beginning of the experiment when one has little or no knowledge of the fluctuations. Therefore, we give the microprocessor an initial critical intensity, which is determined from earlier experience, and provide an initial weight. Now the statistics are not from just the present experiment, but are based on past results as well.

5. RESULTS AND DISCUSSION

Our first experiment was conducted in the Gulf of Maine, and is discussed in detail in Ref. 1. This showed us the large amount of high frequency energy present on the continental shelf. Figure 4 shows the temperature, pressure, and speed records. The top set of curves are hour averages,

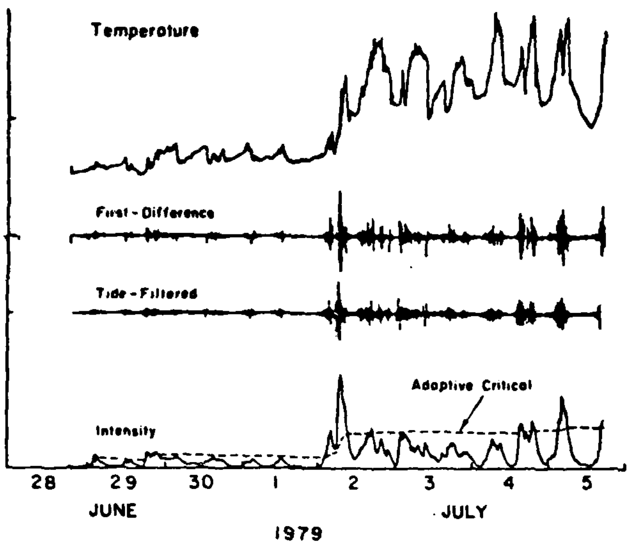

Figure 3. A temperature record from the shelf is shown at the top, and below the first differenced and tide filtered records. The intensity and adaptive critical records are given at the bottom. An event is declared when the intensity exceeds the adaptive critical.

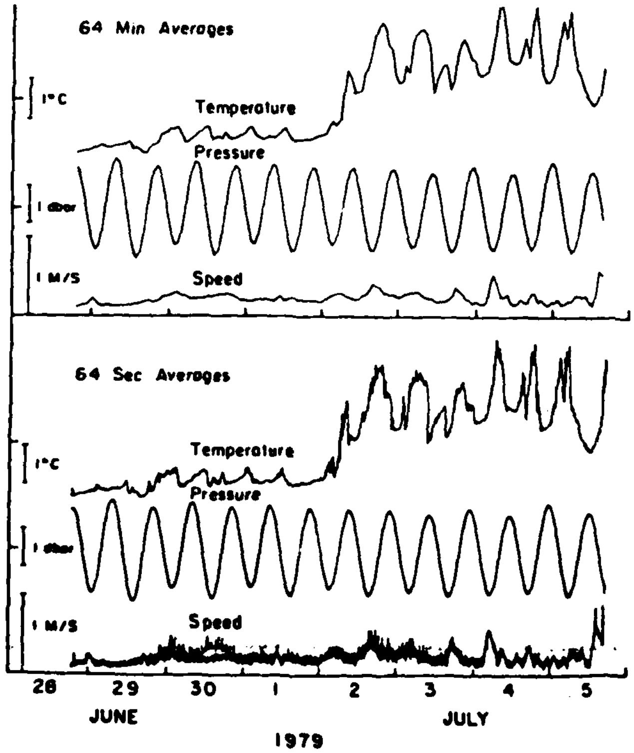

Figure 4. The record from a shelf experiment. The top set of curves resulted from a 64 minute average of the sensor output, and the lower set from a 64 second average.

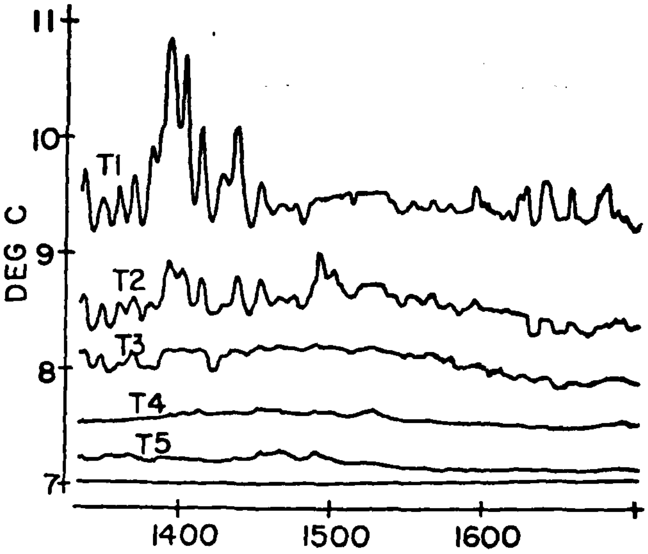

Figure 5. An event record of temperatures. Fifteen second samples of temperature are shown from one event on 9 Oct 1981. The seven minute fluctuations from T1 triggered the event detector.

and show clearly the loss of high frequency signals in hourly averages, as compared with the one minute averages, which give the lower set of curves its "character." In Massachusetts Bay, the high frequency fluctuations (See Figure 5) occur at the Brunt-Vaisala frequency (period of seven minutes) and are as large as the tidal variations. Therefore, to sample these signals properly, one must average over the sample interval to suppress high frequencies. An instantaneous sample every fifteen minutes would be aliased so much as to be useless.

Figure 3 shows the temperature record from the Gulf of Maine, and computer recreations of the first differenced, tide filtered, and intensity series. The adaptive critical is dashed for reference. The peak in the intensity is due to the fluctuations on the front of the warm intrusion, and not by the step itself. This is probably indicative of mixing at the front. The entire nature of the temperature signal changes midway through the record. The pressure record has similar, but less dramatic, changes in intensity. The events in pressure are not synchronized with those of temperature, indicating that different processes have left different signatures on the records, which the event detector selected as "usual" high frequency energy.

The experiment shown in Figures 5 and 6 included six pairs of temperature and conductivity sensors

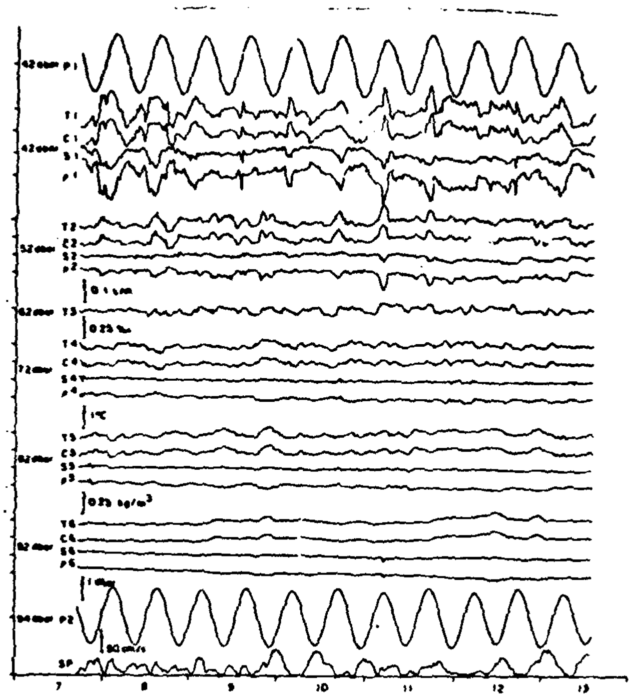

Figure 6. The records from Massachusetts Bay. The twenty minute averages of measured and *calculated series are shown.*

in addition to bottom temperature, pressure, and speed. All the sensors were conditionally sampled, and as might be expected, the conductivity records were essentially the same as temperature. For CODE, we are taking the temperature and conductivity measurements and estimating the salinity from a linearized equation of state. The linearization is good to $\pm$ 0.002 $^{o}/_{oo}$ over the expected range. This salinity is then conditionally sampled as described above. There is no reason why such quantities as Reynolds Stress, or stability could not be estimated, and these quantities conditionally sampled.

The data from Mass Bay (Figure 6) show larger *variations (both high and low frequency)* nearer the thermocline. There is an obvious salinity (and density) feature at 92 dbars on 11 Oct 1980. This was adequately resolved by the twenty minute averages, and the instrument *did not record high* frequency data as a result of this *variation.* The events (See Figure 5 for one) seem to be mainly triggered by internal waves trapped at the Brunt-Vaisala frequency along the thermocline.

One inconvenience we are experiencing is treating the events as a time series. They are really pieces of the high frequency record of different lengths at random times. We find we have to treat each event record separately, which takes considerable analysis time. Still, the information that we are now able to collect is giving us insight into the dynamic process operating on the continental shelf.

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